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1. Introduction

Our eyes sense the environment through movements between visual targets. These movements can be recorded using eye-tracking devices. The data produced by these devices consist of gaze trajectories on observed scenes and are often used in Human-Computer Interaction (HCI) to evaluate visual displays. However, eye-tracking requires expensive devices, can be used only on a limited number of participants and the data are difficult to analyse. Often, only commercially available methods linked to a specific eye-tracking device dominate the analyses (Çöltekin et al. 2010).

Another approach to evaluate visual displays is through the observation of mouse movements while the user explores the display (MacAoidh et al. 2012). Compared to eye movements, mouse movements are easier to automatically record on large scales and much cheaper to obtain. Therefore, also partially relying on hand-eye coordination theory, mouse trajectories are proposed as a proxy for eye tracking (e.g., Huang et al. 2012). However, if and how these two movement types are linked is highly debated.

In this project we systematically investigate the interaction between eye and mouse movements. Various other studies have investigated how these two movement types are connected for non-geographic displays (Rodden et al. 2008, Huang et al. 2012). However, we lack such comparative studies with geographic and spatial tasks, and this paper presents a first step to contribute to this research gap. Furthermore, we propose that methods from trajectory analysis can be used to systematically explore the type and amount of interaction between eye and mouse movements.

The following assumptions enable us to link eye and mouse movement data:

- Both data types can be modelled as trajectories of moving objects (gaze, mouse pointer) despite the fact that the two trajectory types have different characteristics in terms of movement style (jumpy saccadic discrete movements of gaze between fixations vs. smooth mouse movement).
- The two trajectory types are co-located in space and time, i.e. the space of movement for both moving objects is the same (e.g. a 2D computer screen) and they occur simultaneously.
- Both movements are triggered by the same cognitive process of a person investigating a spatial stimulus with the aim to complete a visuo-spatial task.

Based on the above assumptions, we propose that 1) mouse and eye movements can be compared through their co-occurrence in space and time and 2) we can use, adapt and/or develop new trajectory analysis and visualisation methods to compare the two movement types.

In this paper, we test our ideas in a case study where we collected eye and mouse data on very basic visuo-spatial tasks: tracing of various geometric forms on the screen as a simplification of route tracing on a geographic map. The key contribution of this paper is the methodological development for comparison of the two (very different) types of trajectories and how these reflect specific behaviour patterns during visual exploration. For example, theory suggests that the mouse follows the eye in some situations (when target is unknown) while in others the eye follows the mouse (when target is known) (Bieg et al., 2010). In this study, we explore these two behaviours in very basic geometric tasks when there are no known or unknown targets. In the process, we introduce a new methodology: a combination of space-time visualisation and change detection methods for quantification of eye-mouse interaction in such basic tasks. In a parallel experiment(Çöltekin et al. 2014), we explore eye and mouse interaction in map-based visual search tasks combining our method with conventional user experience methods.

2. Experiment – geometric tracing

We collected the data in a controlled lab experiment, where eleven participants were asked to trace a geometric form on the screen. There were four different forms (a circle a rectangle, a star, a flower) and for each of these, the participants had to complete three tasks, thus resulting in a twelve tasks for the total experiment.

The first task consisted of a simple tracing task: participants have seen a geometric form on the screen and were asked to trace it with their mouse without receiving any further information. In the second task they were asked to trace the form while consciously keeping their eyes just ahead of the mouse. In the third task the mouse should consciously be moved first and eyes were to follow (e.g., Figure 1).

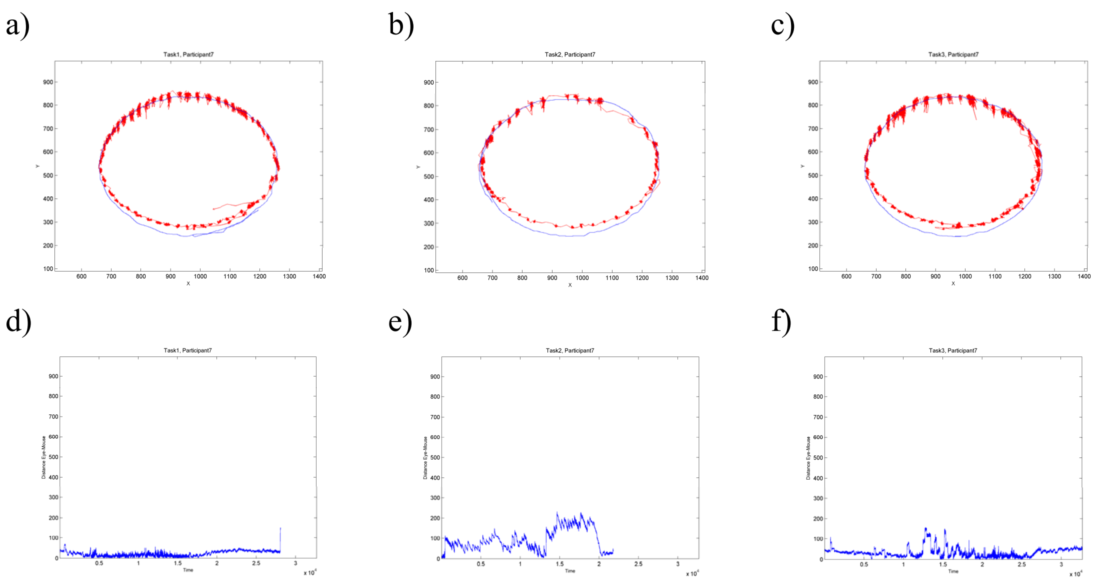

Figure 1. Eye (red) and mouse (blue) trajectories when tracing a circle: a) naturally, b) eye first and c) mouse first. The second row shows plots of *distance between eye and mouse vs. time* for a) natural, b) eye first and c) mouse first tracing. Note that the participants traced a proper circle, not an ellipse (the elliptic appearance above is an artefact of the software we used to produce these charts).

The first step aimed at documenting what people normally do when asked to trace a line, and the following two steps (differences in eye-mouse interaction) were for quantification of the natural movement in the first step. We expected that the second step would prove to be the most difficult (and consequently with least eye-mouse interaction) as it would require the use of peripheral vision and covert attention to complete the task. We further expected to see smooth pursuit[1] (and thus most eye-mouse interaction) in the third step, such that the distance between eye and mouse would be smallest at all times. Figures 1a-c show eye and mouse trajectories of one participant tracing a circle in these three different settings. The differences in eye and mouse movement styles are very clear. Figures 1d-f show the distance between eye and mouse at each moment in time for the same user. In case of this user, these preliminary investigations do not support our hypothesis of seeing smooth pursuit in step 3: the eye and mouse are closest in step 1 (natural tracing). Step 2 does fit with our initial idea in that this should be most difficult and therefore the distance eye-mouse should vary most.

These are however only preliminary observations and for one person only. We continue our data analysis for all the eleven participants and twelve tasks and develop several quantification methods for eye-mouse trajectory interaction in order to be able to understand more fully how different types of tracing work.

3. Quantification of eye-mouse interaction

To quantify the level of interaction between eye and mouse movements, we explore respective trajectories in the 3D conceptual space of a space-time cube (STC). Fig. 2a shows a sideways STC (i.e., time is the lateral axis) for one participant tracing a circle and the difference between the two types of trajectories (eye – red, saccades between fixations; mouse – blue, smooth) can clearly be seen.

In order to be able to compare the two types of movement we calculate the space-time density (Demšar et al. 2014) of each of the two trajectories, as shown in figures 2b and 2c. These aggregations of 3D polylines in STC into a volumetric representation of movement are used to first visualise and second quantify the level of interaction between eye and mouse. For the second part we employ a volumetric generalisation of map algebra which enables us to combine the two densities in various ways, as is often done in two dimensions in change detection in remote sensing. As this is work in progress, we only present two simplest examples of volumetric map algebra calculations here. First, the sum of both densities (fig. 2d) let us visually identify areas in STC where the two trajectories are closest to each other (areas with the highest density sum). Second, the difference between the two densities (fig. 2e) lets us identify areas in STC where eye and mouse were furthest apart. In these and similar volumetric derivations, we quantify the level of eye-mouse interaction through statistical analysis of volumetric values. The simplest example would be the number of voxels over a certain value in the sum volume normalised with volume size: the higher this value, the more interaction there is between eye and mouse.

We are currently investigating a number of possible volumetric generalisations of change detection methods and relevant statistical measures for this purpose.

[1] Smooth pursuit is a specific type of eye movement, where the eyes are continuously following a moving target. It is different from the usual jumpy sequence of saccades and fixations. The reader could try the following to experience smooth pursuit: stretch your right arm as far as possible, extend a finger, focus your vision on the finger. Now move the arm towards the left while not dropping the finger from focus and keeping your head still. Your eyes will be following your finger smoothly – this is the smooth pursuit type of eye movement.

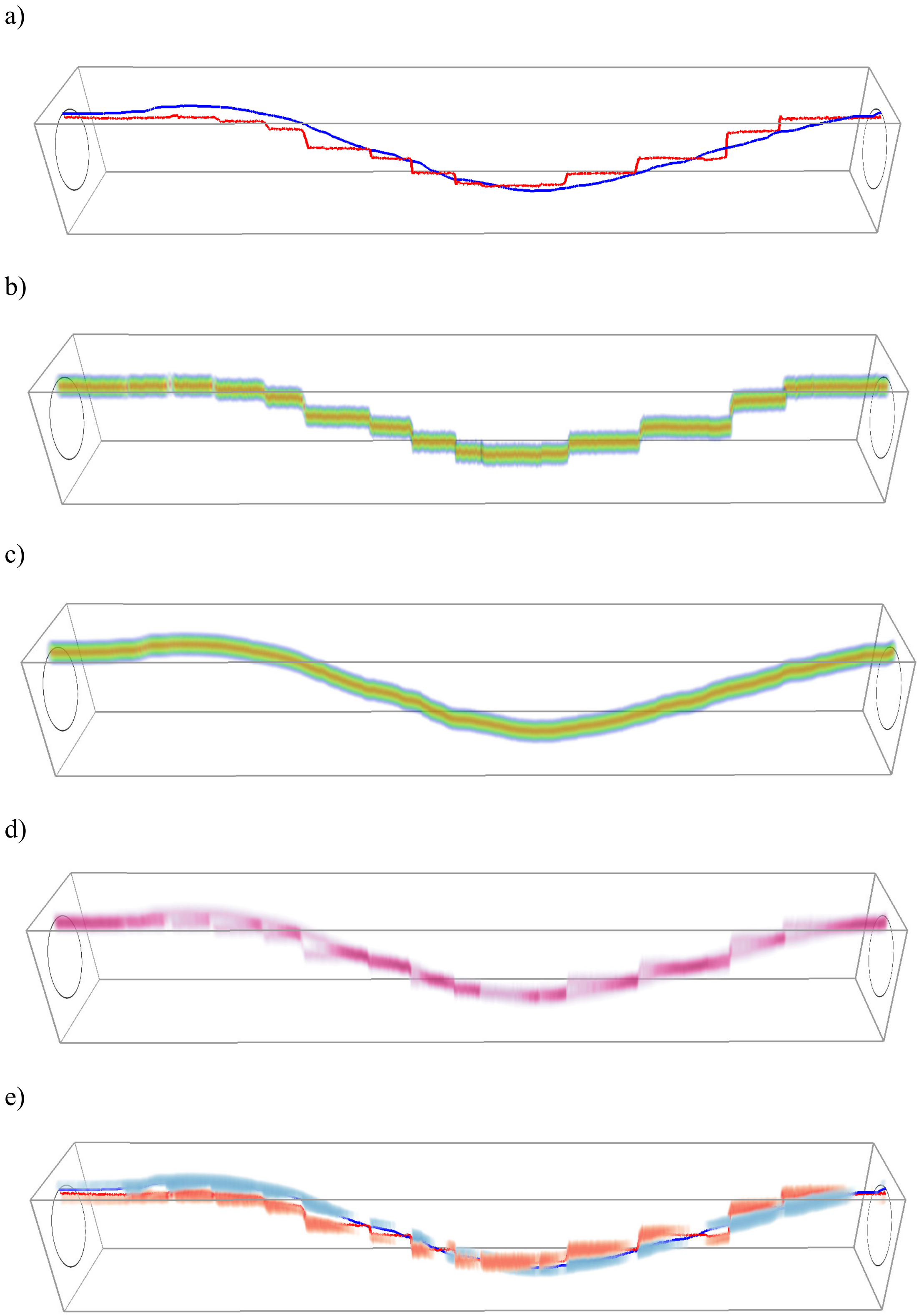

Figure 2. Quantifying eye-mouse interaction with space-time densities. a) STC of eye and mouse trajectories, time starts on the left and proceeds towards the right. b) Space-time density of eye trajectory. c) Space-time density of mouse trajectory. d) Sum of eye and mouse densities. e) Difference of eye and mouse densities, with trajectories.

4. Conclusions and outlook

This paper proposes new methods for evaluation of eye and mouse interaction. Further methodological developments and data analyses are currently in progress. We also expect to be able to use findings from this simplified geometric experiment to serve as the baseline for analysis of eye-mouse interactions in a more complex natural task (i.e. tracing a route on a geographic map) in a follow-up experiment.

We further plan to investigate other change detection methods in remote sensing (Mercier et al. 2009) as a possibility for interaction analysis in the volumetric STC. We will also explore analytical methods for dynamic interaction of trajectories in movement ecology (Long and Nelson 2013) as an alternative.

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